Applied Polyethylene and Polyvinyl Chloride Production Technologies

Presented By
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I. Ethylene Production

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Ethylene Plant
Ethylene Cracking Consideration

1. Basic scheme
2. **Block flow diagram**
3. **Environmental:**

- Latest burner technology (min. NOX, CO).
- Standard NOC regulation practice, de-coke to firebox.
- Minimum quench water blow down with no benzene.
- Segregated contaminates and only water effluent system.
4. **Advanced Control:**

- Advanced regulatory control in DCS.
- Multi variable control.
- Linear and non-linear equation based optimization
  - Online, continuous optimization.
  - Offline, process analysis.
5. **Quench:**

- Secondary oil removal.
- Dilution steam operation.
- Min. waste heat rejection.
- Ripple trays, cost effective, self cleaning vapor/liquid action.
6. **Cracked Gas Compressor:**

- Multistage based on the limitation of max. discharge temperature (90-100°C) which depends on diene’s content.
7. **Primary fractionation:**

- One tower, good wasting of trays to avoid excessive cooling of the column.
- Front end demethanizer.
Ethylene Cracking Consideration (Cont.)

- De-methanizer, front end
  - Lower compressor power
  - Lower investment
  - Improved fractionation efficiency
  - Pressure = 31 bar
  - Top temp. = -98°C
  - Bottom temp. = 10°C
Ethylene Cracking Consideration (Cont.)

- **De-ethanizer:**
  - Reflux condenser at low temp. due to the presence of hydrogen in the over head.
  - Use propane refrigerant to condense and reboil the tower side reboiled tower with ethylene (open loop power advantage).
  - Pressure = 25 bar, Top temp. = -15C, Bottom temp. = 70C.
8. Acetylene hydrogenation, back end reaction

Selective hydrogenation of acetylene (adiabatic reaction).

For high severity, we need reactor feed dilution with de-ethanizer reflux.

CO is injected as a moderator.
Pyrolysis
Pyrolysis Decisions

1. Simple coil design, proven mechanical reliability.

2. Should combines best of 2 concepts.
   a) Small diameter inlet tubes for high heat transfer/ low residence time.
   b) Large diameter outlet tube for minimum coke/ effect on yield.
Yield Parameters

- Olefin Yield
  - Residence Time
  - Hydrocarbon Partial Pressure
  - Temperature Profile
Radiant Coil Relationships

Coil Diameter

RADIANT COIL

Residence Time

Heat Flux
Kinetic Reactions

Primary Reactions → Olefins

Secondary/Tertiary Reactions

Dissociation Products (Methane)
Condensation Products (Fuel Oil)
Selectivity Comparison

- Naphtha, Gas Oil
- NGL
- Ethane/Propane

Selectivity vs. Residence Time
Selectivity Increase

- **Short Residence Time**: shorter coil, heat flux limitations.
- **Higher Temp.**: Metallurgical limits, Shorter Run Length.
- **Steeper Temp. profile**: Small Coil Diameter.
- **Lower HCPP**: Larger coil diameter, higher steam dilution.
Radiant Coils Selection

- High selectivity cracking are not feed flexible.
- Ultra short residence time/ single-pass coil achieves run length 5 to 10 days. It exhibits significant increases in pressure drop throughout the run which is detrimental to yield.
- The moderate short residence time, split coil design, has improved the selectivity to olefins and at the same time, maintained long run lengths, more than 60 days run length at high severity (65-70% ethane conversion).
Radiant Coil Designs

- SRT I
- SRT IV
- SRT II & SRT III
- SRT V (with & without fins)
Coking

1. Surface reactions:
   • Unwanted coking reactions occur. Hence, increasing the surface area increases the coking rate and decreases the run length. Therefore, an optimum exists for each feed stock.
2. Equilibrium Limitations Accelerate Coke Deposition

- It is known that ethane cracking to produce ethylene may be thermodynamic equilibrium limited. In Figure 2, equilibrium conversions as a function of coil outlet temperature and steam-to-oil ratios are shown.

\[
\text{C}_2\text{H}_6 \rightleftharpoons \text{C}_2\text{H}_4 + \text{H}_2
\]
Coking (Cont.)

Equilibrium Ethane Conversion

Conversion, %

Temperature, Deg. C

COP, Psia-S/O, wt/wt

28PSIA-0.3  40PSIA-0.3  40PSIA-0.5
Coking (Cont.)

3. Flow Distribution

a) A single manifold feeds many single pass coils with many parallel tubes in the first pass. The flow to each tube is controlled by the pressure drop in that tube. For a long coil, the pressure drop in each tube of the first pass is significant and the coke deposition is very small from start of run (SOR) to end of run (EOR) to low ethane conversion (<15%) in that pass. Where coke deposition is significant, (large tube) is used.
Uniform Flow Venturi Principle

FLOW $\propto$ VENTURI DIAMETER, UPSTREAM DENSITY

$P_2/P_1 \leq 0.9$
Coking (Cont.)

b) Contaminants in the ethane feed like green oil can increase the coking rate near the inlet of the coil, therefore, for a successful ethane cracking, no green oil should be present.

c) Short run length for ethane cracking has been attributed to iron and chromium migration, plays some role in coke formation.
Quench Exchanger

• Rapid quenching to achieve high heat transfer and reduce the secondary reactions.
• Coking rate reduction.
• Online decoking.
• Stage wise diameter increase throughout the radiant coil – transfer line exchanger – to accommodate thermal and molecular expansion and coke lay down.
Quench Exchanger, (cont.)

• A single stage shell and tube heat exchanger is used to cool the heater effluent rapidly. During this process, high pressure steam is generated.

• Coking in the radiant coils and in the transfer line exchangers (TLE) cannot be avoided. But the rate of deposition can be controlled by proper design.
Economic Design Aspects
Economic Definitions

- **Selectivity:** $\sum$ (Ethylene + Propylene + Butadiene) produced at constant severity (conversion).
- **Severity:** % of Feedstock converted to cracked products.
- **Specific Energy Consumption:** Total Net Energy to produce unit quantity of Ethylene
  
  No G.T = 3300 kCal/ kgC\(_2\)H\(_4\)
- **Specific Power Consumption:** $\sum$ Compressor Power per unit quantity of Ethylene, Ranges from 0.55 – 0.62 KW/ kgC\(_2\)H\(_4\)
Once thru ethylene yield vs. % Conversion
Ultimate ethylene yield vs. % Conversion

- Ultimate Ethylene Yield Wt%:
  - 85.1
  - 83.6
  - 81.9
  - 79.9

- % Conversion C2H6:
  - 50
  - 55
  - 60
  - 65
  - 70

100% C2H6 FEED
Ethane Traffic vs. Conversion

Feed F → Conversion C → Recovery → Products

Recycle R

\[ R = F \cdot \frac{I - C}{C} \]

<table>
<thead>
<tr>
<th>C</th>
<th>R+F</th>
<th>RATIO</th>
</tr>
</thead>
<tbody>
<tr>
<td>.70</td>
<td>1.43</td>
<td>BASE</td>
</tr>
<tr>
<td>.65</td>
<td>1.54</td>
<td>1.08</td>
</tr>
<tr>
<td>.60</td>
<td>1.66</td>
<td>1.16</td>
</tr>
<tr>
<td>.55</td>
<td>1.82</td>
<td>1.27</td>
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</tbody>
</table>
Ethane Conversion Optimization

Conversion

Once-thru yield
Ultimate yield
Specific energy
Investment
Traffic
Operating Parameters
Operating Parameters

- Olefin production is promoted by high temp. and short residence time and cracking pressure.

- Cracking pressure is controlled by the suction pressure of compressor and $\Delta P$ between outlet of furnace and the compressor.

If cracking pressure decreases: olefin yield increase, furnace and quench boiler coking decrease.
Operating Parameters (Cont.)

• High pressure steam generation:
  – At the outlet of the furnace, effluents are cooled down to 350-400 °C in a quench boiler (double pipe exch.) with generation of high pressure steam 120 bar.
Table 1

Design and Operating Conditions for Ethane Cracking (CR)

<table>
<thead>
<tr>
<th></th>
<th>Design</th>
<th>Operation</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Average</td>
</tr>
<tr>
<td>Feed, Mol %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CH4</td>
<td>1.5</td>
<td>0.95 (0.76 - 1.38)</td>
</tr>
<tr>
<td>C2H6</td>
<td>97.0</td>
<td>97.4 (95.7 - 98.5)</td>
</tr>
<tr>
<td>C2H4</td>
<td>-</td>
<td>1.04 (0.01 - 3.0)</td>
</tr>
<tr>
<td>C3H8</td>
<td>1.5</td>
<td>0.6 (0 - 0.95)</td>
</tr>
<tr>
<td>S/O ratio, wt/wt</td>
<td>0.30</td>
<td>0.303 (1531 - 1560)</td>
</tr>
<tr>
<td>COT, deg. F</td>
<td>1521</td>
<td>1540 (59.8 - 68.9)</td>
</tr>
<tr>
<td>Conversion, %</td>
<td>65</td>
<td>64 (525 - 533)</td>
</tr>
<tr>
<td>TLE outlet temp., F</td>
<td>533</td>
<td>530 (35216 - 38537)</td>
</tr>
<tr>
<td>HP steam, lb/h</td>
<td>37367</td>
<td>37350</td>
</tr>
<tr>
<td>Run length, days</td>
<td>70</td>
<td>72</td>
</tr>
</tbody>
</table>
Technology Improvements
Technology Improvements

1. **Reduction of Energy consumption**
   a) Improve furnace thermal efficiency more than 95%.

2. Reduction of steam demand by reducing compressor power required per ton ethylene, less than 650 kWh/t/h.

3. **Tertiary refrigerant application.**

4. **High capacity pyrolysis heaters with high selectivity.**

5. **Pyrolysis radiant coil modification**
6. Ethylene Feed Pretreatment:

- Mercury removal
  **RAM Process:**
- 2 catalytic reactors, to trap Hg
- 1\textsuperscript{st} reactor: Organometallic Hydrogenolysis of Hg To elemental Hg
- 2\textsuperscript{nd} reactor: Mercury trapping medium
Technology Improvements (Cont.)

7. Integration of a gas turbine driver and reconfiguration of both steam system and pyrolysis furnace heat recovery system

Two cases:

- Gas turbine exhausts into a boiler, while pyrolysis furnace use combustion air preheated with flue gas.
- Gas turbine exhaust into the pyrolysis furnaces and supplementary combustion air for the furnace is preheated with steam.
Export     Power

W.H.B.

G. Turbine

Standalone
Combined Cycle/
Cogeneration
Polyethylene
Production
Polyethylene Production

Polyethylene:

Partially Crystalline

Uses: Tubing, Film, Bottle, Cups, Electrical Insulation and Packing.
Fluid Bed Process

Process Summary

Catalyst Preparation
- Ziegler-Natta Catalyst Precursors
- Chromium Catalyst Precursors

Prepolymerisation
- Hydrogen
- Ethylene
- Reactor
- Fluid Bed Reactor
- Gas Cooler
- Compressor
- Air

Polymerisation
- Ethylene Hydrogen Comonomer
- Gas Cooler
- Gas recycle
- Degasser
- Treater

Extrusion/Product Despatch
- Additives
- Extruder/Pelletiser
- SILO
- Product Despatch
Polyethylene Production

Basic ethylene polymerization mechanism using Ziegler Catalyst:

• In a Ziegler catalyst, Ti (III) must be activated by an organo aluminum compound called Co-Catalyst.

• The active site is built through the alkylation of titanium by organo aluminum compound.

• In the reaction propagation process, insertion of ethylene into Ti-C bond, heterogen. polymerization.
Termination step performed to control the final M.Wt. of the polymer by:

- Self termination
- Chain transfer to monomer
- Hydrogen chain transfer, H-Ti.
In a Ziegler-Natta catalyst, Titanium (III) is potentially active.

However, it must be activated by an organo aluminum compound. i.e. the co-catalyst.
Constitution of the Active Site

- The active site is built through the alkylation of titanium by the organo aluminum compound (TnOA).
Propagation

Physical adsorption of monomer

Monomer insertion

Inserted monomer

Alkyl from TnOA

Polymer chain
Termination

- The polymer growth is terminated by means of hydrogen chain transfer.
- This is done to control the final molecular weight of the polymer.
Polymer Withdrawal and Conditioning
Extruder Feeds
Pelletisation

Flow diagram:

- Feeds
- N2
- M-840
- Pelletiser water feed
- Atmosphere
- B-847
- Pelletiser Water outlet
- Oversize
- S-847
- F-850
- Rerun Pellets to F-855
- Homogenisation
- C-850
Silos / Despatch
Reaction Control Parameters
Gas Flow in the Fluidised Bed

- Gas outlet
- Fluidising gas
- Fluidisation grid
- Bubble size increases
- Coalescence zone
- Jet penetration zone
- Fully coalesced
- Coalescence
# Main Properties of Polyethylene

<table>
<thead>
<tr>
<th>Property</th>
<th>HDPE</th>
<th>LDPE</th>
<th>LLDPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Melt Index 6/10 min</td>
<td>0.01-80</td>
<td>0.2-70</td>
<td>0.2-50</td>
</tr>
<tr>
<td>Density  g/cm³</td>
<td>0.960</td>
<td>&lt; 0.920</td>
<td>&lt; 0.920</td>
</tr>
<tr>
<td>Molecular Structure</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Short Chain Branches/1000 C</td>
<td>0-5</td>
<td>15-25</td>
<td>15-25</td>
</tr>
<tr>
<td>Length</td>
<td>C₂ or C₄</td>
<td>C₁, C₂, C₃, C₄</td>
<td>C₂ or C₄ or C₆</td>
</tr>
<tr>
<td>Long Chain Branches/Mol</td>
<td>~ 0</td>
<td>~ 30</td>
<td>~ 0</td>
</tr>
<tr>
<td>Morphology</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Crystalline mp°C</td>
<td>130</td>
<td>108</td>
<td>123</td>
</tr>
<tr>
<td>- Spherulite Size</td>
<td>LARGE</td>
<td>SMALL</td>
<td>LARGE</td>
</tr>
<tr>
<td>Tensile Strength (PSI)</td>
<td>3,500-4,500</td>
<td>1,000-2,000</td>
<td>3,000-4,500</td>
</tr>
<tr>
<td>Elongation (%)</td>
<td>100-1,000</td>
<td>300-600</td>
<td>600-700</td>
</tr>
<tr>
<td>Shore D Hardness</td>
<td>60-70</td>
<td>41-45</td>
<td>44-48</td>
</tr>
<tr>
<td>Maximum Service Temperature (°C)</td>
<td>110-130</td>
<td>80-95</td>
<td>90-105</td>
</tr>
</tbody>
</table>
Process Improvements

• 1) Spheriline Gas Phase Technology, Basell Technology, high performance and bimodal grades based on applied Molecular Model

  VLDPE-HDPE  Density: (0.900-0.96)

  MI:      (0.1-100gr/10)

• Prepolymerization step, slurry phase

• 2 Gas Phase Reactor
Process Improvements, (Cont.)

- 2. Borstar Polyethylene Process, Borialis,
- Bimodal and Unimodal products
- Density: 0.917-0.970
- MI: 0.1-100
- MWD: narrow – Broad
- Prepolymerization
- Loop reactor
- Gas phase reactor
**PE Processing**

**LLDPE:**

- Tm is higher 15 C for LLDPE of same density as LDPE.
- T.S. at break is higher. T.S. at yield is about the same of the same density. (down gauging that is justified on T.S. at break basis, lead to products that stretch unacceptably under load).
- Stiffer for the same thickness of LDPE film.

**HDPE:**

- Mechanical properties of HDPE grade applications are affected by M.Wt, MI and sp. gr.
Main Additives

1) Anti Oxidants:
   • Degrading Agents: Oxygen and Sunlight.
     Most polymer processing is above 180 C
     Auto-oxidative free radical reaction
     Thiols & Phenols.

2) Heat Stabilizers:
   Epoxy base or Ca-Zn, Sb, ....
Additives, (Cont.)

3) Light Stabilizers:

Solar Radiation

• Photo-oxidation depends on:
  Stabilizer Type
  Degradation Mechanism

Classes:
  a) UV Screeners and/or Absorbers
  b) Free Radical Scavengers
Additives, (Cont.)

4) Fillers:

Crystalline or Amorphous, e.g. CaCo3, TiO2, Glass beads.

Objectives: Plastic properties & Cost Reduction

**Impact on polymers:**

High Young’s Modulus
Better Thermal Stability
Reduction of fracture strain under tensile load
Non-uniformity in some applications
### Film Product Range

<table>
<thead>
<tr>
<th>MFR</th>
<th>Density</th>
<th>Butene Copolymers</th>
<th>Hexene (4MP-1) Copolymers</th>
</tr>
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<tbody>
<tr>
<td>Blown Film</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.6</td>
<td>920</td>
<td>LL0205</td>
<td>LL7206</td>
</tr>
<tr>
<td>0.9</td>
<td>920</td>
<td>LL0209</td>
<td>LL7209</td>
</tr>
<tr>
<td>0.9</td>
<td>924</td>
<td>LL0209</td>
<td>LL7409</td>
</tr>
<tr>
<td>0.8</td>
<td>926</td>
<td>LL0410</td>
<td></td>
</tr>
<tr>
<td>0.6</td>
<td>928</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.9</td>
<td>936</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HLMI 14.0</td>
<td>939</td>
<td>HD 3802-2</td>
<td>LL7606</td>
</tr>
<tr>
<td>HLMI 9.0</td>
<td>950</td>
<td>HD 5001-2</td>
<td>LL7909</td>
</tr>
<tr>
<td>Cast Film</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.4</td>
<td>920</td>
<td>LL0220</td>
<td>LL6130</td>
</tr>
<tr>
<td>2.0</td>
<td>924</td>
<td></td>
<td>LL7420</td>
</tr>
<tr>
<td>4.0</td>
<td>930</td>
<td>LL0640</td>
<td></td>
</tr>
</tbody>
</table>

Mainly for:
- Lean blends with LDPE
- General purpose
- Lamination
- Cast stretchwrap

Mainly for:
- Rich blends or pure
- Heavy duty packaging
- Higher Strength/Stiffness
- Higher temperature resistance

A range of additive formulations is available to meet final application requirements (slip, antiblock, processing aid, cling agent,...)
### Key Applications for Film Grades

<table>
<thead>
<tr>
<th>Application</th>
<th>Property Requirements</th>
<th>Recommended Grades</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sacks</td>
<td>Impact strength, Tensile strength, Puncture resistance</td>
<td>LL0209AA (medium duty), LL7206AF (heavy duty), HD3802EA (blends)</td>
</tr>
<tr>
<td>Stretchwrap</td>
<td>Puncture resistance, TD tear strength, Low gel level</td>
<td>LL0220AA, LL6130AA (cast), LL7209AA, LL0209AA (blown)</td>
</tr>
<tr>
<td>Carrier bags</td>
<td>Tensile strength, Puncture resistance</td>
<td>LL0410KJ, HD5001FA, LL7606LJ</td>
</tr>
<tr>
<td>Lamination film</td>
<td>Hot tack, Good optical properties, Low gel level, Low odour</td>
<td>LL1209AA/KJ, LL0209LL, LL7909AA/KJ</td>
</tr>
<tr>
<td>Produce bags</td>
<td>Good optical properties, Puncture resistance</td>
<td>LL0209KJ, LL7409KJ</td>
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</table>
# Moulding Product Range

<table>
<thead>
<tr>
<th>Injection</th>
<th>MFR</th>
<th>Density</th>
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<tbody>
<tr>
<td>HD5120EA</td>
<td>1.9</td>
<td>950</td>
</tr>
<tr>
<td>HD5050EA</td>
<td>4.5</td>
<td>950</td>
</tr>
<tr>
<td>HD5740EA</td>
<td>4</td>
<td>957</td>
</tr>
<tr>
<td>HD6070EA</td>
<td>7.5</td>
<td>960</td>
</tr>
<tr>
<td>HD6070UA</td>
<td>7.5</td>
<td>960</td>
</tr>
<tr>
<td>HD5211EA</td>
<td>11</td>
<td>952</td>
</tr>
<tr>
<td>BD24250AA</td>
<td>25</td>
<td>926</td>
</tr>
<tr>
<td>BD30500AA</td>
<td>50</td>
<td>930</td>
</tr>
</tbody>
</table>

- **Heavy Duty applications**
- **General packaging crates, boxes**
- **Flexible lids and containers**
### Key Applications for Moulding Grades

<table>
<thead>
<tr>
<th>Application</th>
<th>Property Requirements</th>
<th>Recommended Grades</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crates, heavy duty cases</td>
<td>High stiffness</td>
<td>HD6070 UA</td>
</tr>
<tr>
<td></td>
<td>Impact strength</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ESCR and UV resistance</td>
<td></td>
</tr>
<tr>
<td>Large bins, waste bins</td>
<td>Very high strength</td>
<td>HD5740 UA</td>
</tr>
<tr>
<td></td>
<td>ESCR and UV resistance</td>
<td></td>
</tr>
<tr>
<td>Screw stoppers</td>
<td>High ESCR</td>
<td>HD5050 EA</td>
</tr>
<tr>
<td></td>
<td>Tightness</td>
<td>HD5120 EA</td>
</tr>
<tr>
<td></td>
<td>Low taint</td>
<td>HD6070EA (mineral water)</td>
</tr>
<tr>
<td>Thin wall containers</td>
<td>Fast injection</td>
<td>HD5226 EA</td>
</tr>
<tr>
<td></td>
<td>Surface appearance</td>
<td>HD5150EA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>BD24250 AA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>BD30500 AA</td>
</tr>
<tr>
<td>Rotomoulded tanks, silos, drums</td>
<td>Toughness</td>
<td>HD3840 UA</td>
</tr>
<tr>
<td></td>
<td>UV Resistance</td>
<td>HD2840 UA (stress)</td>
</tr>
<tr>
<td></td>
<td>Easy mould release</td>
<td></td>
</tr>
<tr>
<td>Blow moulded detergent bottles</td>
<td>Good processability</td>
<td>HD5402-5EA</td>
</tr>
<tr>
<td></td>
<td>High ESCR</td>
<td>HD5403-4EA</td>
</tr>
<tr>
<td>Bulk containers</td>
<td>Impact strength</td>
<td>HD5301-2EA</td>
</tr>
<tr>
<td></td>
<td>ESCR</td>
<td></td>
</tr>
</tbody>
</table>

*Market Leader*
# HD/LLDPE Product Range for Extrusion Applications

<table>
<thead>
<tr>
<th>Category</th>
<th>Product Code</th>
<th>MFI</th>
<th>HMRI</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Blow Moulding</strong></td>
<td>HD 5402-5EA</td>
<td>0.2</td>
<td>955</td>
<td>Containers 0-5l - sheets</td>
</tr>
<tr>
<td></td>
<td>HD 5403-4EA</td>
<td>0.35</td>
<td>955</td>
<td>Containers 0-5l (high flow)</td>
</tr>
<tr>
<td></td>
<td>HD 5702-4EA</td>
<td>0.2</td>
<td>958</td>
<td>Containers 0-5l (high stiffness)</td>
</tr>
<tr>
<td></td>
<td>HD 5301-2EA</td>
<td>HLMI 10</td>
<td>953</td>
<td>Containers up to 2000l</td>
</tr>
<tr>
<td><strong>Film</strong></td>
<td>HD 5001-2EA</td>
<td>HLMI 9</td>
<td>950</td>
<td>Thin film</td>
</tr>
<tr>
<td></td>
<td>HD 3802-2EA</td>
<td>HLMI 14</td>
<td>939</td>
<td>Medium duty packaging</td>
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<tr>
<td><strong>Wire &amp; Cable</strong></td>
<td>LL 2406-1AA(1)</td>
<td>0.6</td>
<td>924</td>
<td>Jacketing (low density)</td>
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<tr>
<td></td>
<td>HD 4002 EX(1)</td>
<td>0.25</td>
<td>933</td>
<td>Jacketing (medium density)</td>
</tr>
<tr>
<td><strong>Pipe</strong></td>
<td>HD 5402-1EA</td>
<td>0.2</td>
<td>955</td>
<td>Ducting pipe</td>
</tr>
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<td></td>
<td>LL 2406-1AA(1)</td>
<td>0.6</td>
<td>924</td>
<td>Small diameter water pipe</td>
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<tr>
<td></td>
<td>HD 4401-1EX(1)</td>
<td>HLMI 11</td>
<td>945</td>
<td>Water/gas pipe (high density)</td>
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<tr>
<td></td>
<td>HD 3902-1EX(1)</td>
<td>HLMI 19</td>
<td>938</td>
<td>Water/gas pipe (medium density)</td>
</tr>
</tbody>
</table>

(1) Base resin for compound
## Extrusion Applications
### Product Range

| Wire & Cable | LL 2406-1AA<sup>(1)</sup> | 0.6 | 924 | Jacketing (low density) |
| HD 4002 EX<sup>(1)</sup> | 0.25 | 933 | Jacketing (medium density) |

| Pipe | HD 5402-1EA<sup>(2)</sup> | 0.2 | 955 | Ducting pipe |
| LL 2406-1AA<sup>(1)</sup> | 0.6 | 924 | Small diameter water pipe<sup>(2)</sup> |
| HD 4401-1EX<sup>(1)</sup> | HLM 11 | 945 | Water/gas pipe (high density)<sup>(2)</sup> |
| HD 3902-1EX<sup>(1)</sup> | HLM 19 | 938 | Water/gas pipe (medium density)<sup>(2)</sup> |

<sup>(1)</sup> Base resin for compound

<sup>(2)</sup> Not commercialised in Europe
## Injection and Rotational Moulding Product Range

<table>
<thead>
<tr>
<th>Injection</th>
<th>MFR</th>
<th>Density</th>
<th>Applications</th>
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<tbody>
<tr>
<td>HD5120EA</td>
<td>1.9</td>
<td>950</td>
<td>Screw stoppers</td>
</tr>
<tr>
<td>HD5050EA</td>
<td>4</td>
<td>950</td>
<td>Closures, technical parts</td>
</tr>
<tr>
<td>HD5740EA</td>
<td>4</td>
<td>957</td>
<td>Boxes, dustbins (UV)</td>
</tr>
<tr>
<td>HD6070EA</td>
<td>7.5</td>
<td>960</td>
<td>General purpose</td>
</tr>
<tr>
<td>HD6070UA</td>
<td>7.5</td>
<td>960</td>
<td>Crates, toys (UV)</td>
</tr>
<tr>
<td>HD5211EA</td>
<td>11</td>
<td>952</td>
<td>Houseware, toys</td>
</tr>
<tr>
<td>HD5813EA</td>
<td>13</td>
<td>956</td>
<td>Houseware</td>
</tr>
<tr>
<td>HD5218EA</td>
<td>18</td>
<td>952</td>
<td>Food containers, houseware</td>
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<tr>
<td>HD5226EA</td>
<td>26</td>
<td>952</td>
<td>Thin-walled products</td>
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<tr>
<td>HD5150EA</td>
<td>55</td>
<td>948</td>
<td>Disposable cups</td>
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<tr>
<td>BD24250AA</td>
<td>25</td>
<td>926</td>
<td>Lids, closure</td>
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<tr>
<td>BD30500AA</td>
<td>50</td>
<td>930</td>
<td>Ice cream boxes, margarine tubs</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Rotational</th>
<th>MFR</th>
<th>Density</th>
<th>Applications</th>
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</thead>
<tbody>
<tr>
<td>HD3840UA</td>
<td>4</td>
<td>938</td>
<td>Tanks, hoppers, silos</td>
</tr>
<tr>
<td>HD2840UA</td>
<td>4</td>
<td>930</td>
<td>Tanks, hoppers, silos, drums</td>
</tr>
<tr>
<td>HD3560UA</td>
<td>6</td>
<td>933</td>
<td>Toys</td>
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</table>
## PE Local Market Survey

**HDPE** 350,000 – 400,000 T/Y

<table>
<thead>
<tr>
<th>APPLICATION</th>
<th>% OF TOTAL</th>
<th>DENSITY RANGE</th>
<th>MFI RANGE</th>
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<tbody>
<tr>
<td><strong>FILM</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>* MMW</td>
<td>10</td>
<td>0.930 – 0.965</td>
<td>0.2 – 1.6</td>
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<tr>
<td>* HMW</td>
<td>10</td>
<td>0.930 – 0.965</td>
<td>0.1 – 0.15</td>
</tr>
<tr>
<td><strong>INJECTION M.</strong></td>
<td>32</td>
<td>0.935 – 0.965</td>
<td>2 – 55</td>
</tr>
<tr>
<td><strong>BLOW M.</strong></td>
<td>39</td>
<td>0.940 – 0.965</td>
<td>0.1 – 0.7</td>
</tr>
<tr>
<td><strong>PIPE</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>* GAS PIPES</td>
<td>1.5</td>
<td>0.933 – 0.960</td>
<td>0.2 – 0.8</td>
</tr>
<tr>
<td>* DRAINAGE PIPE</td>
<td>1.5</td>
<td>0.933 – 0.960</td>
<td>0.2 – 0.8</td>
</tr>
<tr>
<td><strong>WIRE &amp; CABLES</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>* JACKETING &amp; INS.</td>
<td>1</td>
<td>0.933 – 0.950</td>
<td>0.2 – 0.8</td>
</tr>
<tr>
<td>* CROSSLINKADE</td>
<td>5</td>
<td>0.933 – 0.945</td>
<td>1.2 – 5</td>
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</table>
PE Local Market Survey (Cont.)

L.LDPE  80,000 – 90,000 T/Y

<table>
<thead>
<tr>
<th>APPLICATION</th>
<th>% OF TOTAL</th>
<th>DENSITY RANGE</th>
<th>MFI RANGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>FILM</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>* L.DUTY FILM</td>
<td>40</td>
<td>0.920 - 0.930</td>
<td>1.5 - 2.2</td>
</tr>
<tr>
<td>* H.DUTY FILM</td>
<td>60</td>
<td>0.918 - 0.930</td>
<td>0.3 - 1.5</td>
</tr>
</tbody>
</table>
Polyvinyl Chloride Production
Polyvinyl Chloride Production

Uses: architectural uses (windows, frames, etc...), plasticized to make artificial leather, hoses and clothing.
Polyvinyl Chloride Production (Cont.)
Polyvinyl Chloride Production (Cont.)

I. Raw Material Storage

A. Hot & Cold De-mineralized Water
B. Fresh & Recovered Vinyl Chloride Monomer (VCM)
C. buffer
D. Emulsifier(s)
E. Catalyst(s)
F. Shortstop Solution
G. Coating
Polyvinyl Chloride Production (Cont.)

II. Charging & Polymerization

A. Poly Charge Procedure
B. Water and VCM Chargning
C. Additive (or pigment) charging
D. Poly & Polymerization Control
Polyvinyl Chloride Production (Cont.)

III. Slurry Transfer
   A. Blow Down Tanks

IV. Slurry Stripping
   A. Flash Column Feed Tanks
   B. Slurry Stripping Column
   C. Blend tanks
Polyvinyl Chloride Production (Cont.)

V. drying

A. Centrifuge
B. Rotary Dryer
C. Dust Collection
D. Screening
Polyvinyl Chloride Production (Cont.)

VI. VCM Recovery

A. Batch Recovery
B. Continuous Recovery
C. Vent Gas Recovery

VII. Waste Water Stripping
Polyvinyl Chloride Production
(Cont.)

VIII. Process Quality Control

A. Specifications

B. Control Charting

C. Process Changes for quality Control
Control Charting

Technique to monitor specification properties and determine when process changes should be made to maintain specification.

Process change is made when:

- Data point exceeds $3 \, S_t$.
- 2 of 3 successive data points exceed $2 \, S_t$.
- 4 of 5 successive data points exceed $1 \, S_t$. 
## E.P.C. Product Specification

<table>
<thead>
<tr>
<th></th>
<th>K-70</th>
<th>K-67</th>
<th>K-61</th>
<th>K-57</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>INHERENT VISCOSITY (I.V)</strong></td>
<td>0.98 - 1.05</td>
<td>0.90 - 0.94</td>
<td>0.75 - 0.78</td>
<td>0.66 - 0.70</td>
</tr>
<tr>
<td><strong>HEAT LOSS (H.L)</strong></td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td><strong>POROSITY (D.O.P) ml/gm</strong></td>
<td>0.27 - 0.37</td>
<td>0.20 - 0.32</td>
<td>0.17 - 0.27</td>
<td>0.17 - 0.27</td>
</tr>
<tr>
<td><strong>DENSITY gm/ml</strong></td>
<td>0.47 - 0.53</td>
<td>0.50 - 0.56</td>
<td>0.50 - 0.56</td>
<td>0.50 - 0.56</td>
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<tr>
<td><strong>SONIC SIFTER</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R 40 % MAX.</td>
<td>1</td>
<td>1</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>R 60 % MAX.</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>T 140 % MAX.</td>
<td>25</td>
<td>25</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>APS ± 10</td>
<td>155</td>
<td>160</td>
<td>135</td>
<td>135</td>
</tr>
<tr>
<td>PSD</td>
<td>&lt; 25</td>
<td>&lt; 25</td>
<td>&lt; 30</td>
<td>&lt; 30</td>
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<tr>
<td><strong>DARK RESIN</strong></td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
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<tr>
<td><strong>RVCM</strong></td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td><strong>FISH EYES</strong></td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
</tbody>
</table>
1. PVC Compounding

i. Fabrication Equipment:

1. Mixing: batch banburys, kneaders, mixing rolls.

2. Extrusion: single or twin screw.

3. Molding: single or twin screw injection molding; and compression molding.

1. PVC Compounding (Cont.)

ii. Additives:

Cross linking activation:

organic peroxide.

Cross linking agents:

- Diallyl phthalate
- Diallyl maleate
- Silanes
- Bivalent metal soaps
1. PVC Compounding (Cont.)

- **Plasticizers:**
  - Objectives: Lower Tg, softer product
  - Esters of poly-carboxylic acid with aliphatic branching
  - Two classes:
    - **Low M.Wt.:** DOP, DEHP, DBP, DIBP
    - **High M.Wt.:** DINP, DIDP
  - Selection is based on:
    - Lower toxicity, compatibility, non-volatility, and costs.
  - New trend; Biobased plasticizers, Proviron.
1. PVC Compounding (Cont.)

**Stabilizers:**

1. Lead base (tri basic lead sulfate, lead stearate).
2. Metal soaps (cd-zn soap, cd-Ba system).
3. Organotin compounds (octyltin, Ca-Zn, lubricant).
4. non-metal stabilizer, secondary stabilizers (organic phosphities, epoxy compounds).
1. PVC Compounding (Cont.)

**Flame retardants:**

- Phosphate esters or chlorinated hydrocarbons are used to overcome the flammability problems of plasticizers.

**Processing acids:**

- To reduce the melt viscosity of PVC compound and make it easier to process/ (PE, epoxy compounds and ABS).
1. PVC Compounding (Cont.)

**Antistatic agents:**

- PVC is poor electrical conductor and may readily accumulate static charges.
- Friction is the most common source of charge generation. Static charges are responsible for handling difficulties in film processing operations.
- Internal or external application of antistatic agents are similar to lubricants. (amides, amines, PE glycol derivatives and quaternary ammonium compounds).
Impact Modifiers:

• Vital for rigid applications.
• Can be incorporated into PVC by dry blend or melting compounding.
• Can also be incorporated during polymerization by adding rubber emulsion.
2. Compounding Processes

1. Extrusion

   a) Rigid PVC

      i. Pipes: high thermal stability, IV 0.88 – 0.95
      ii. Profiles: high thermal stability, IV 0.88 – 1.12
      iii. Plates: high thermal stability, clarity, IV 0.74 – 0.95
      iv. Film: high thermal stability, IV 0.74 – 0.82
2. Compounding Processes (Cont.)

b) **Flexible PVC**

i. Cables: high plasticizer absorption, good electrical properties, IV 1.00 – 1.12.

ii. Profiles: high plasticizer absorption, IV 0.9 – 1.12

iii. Plates: high clarity, IV 0.9 – 0.98
2. Compounding Processes (Cont.)

2. **Blow Molding**
   i. Bottles: high thermal stability and color, V.I. 0.6 – 0.82.

3. **Injection Molding**
   i. Rigid application: high thermal stability, IV 0.6 – 0.82.
   ii. Flexible applications: high plasticizer absorption, IV 0.9 – 1.04.

4. **Calendaring flexible applications:**
   i. high plasticizer absorption and color, IV 0.72 – 1.04.
## Rigid PVC Compound Specifications

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Pipes</td>
<td>Corrugated</td>
<td>Yellow</td>
<td>1.47 max.</td>
<td>455 Kg/Cm² min.</td>
<td>140 % min.</td>
<td>&gt; 12 mns</td>
<td>55 J/m min.</td>
<td>700 Kg/Cm² min.</td>
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<tr>
<td></td>
<td>Pressure</td>
<td>Grey</td>
<td>1.40</td>
<td>455</td>
<td>145</td>
<td>&gt; 12 mns</td>
<td>65 J/m min.</td>
<td>750 Kg/Cm² min.</td>
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<tr>
<td></td>
<td>Drainage</td>
<td>Grey</td>
<td>1.48</td>
<td>450</td>
<td>148</td>
<td>&gt; 12 mns</td>
<td>57 J/m min.</td>
<td>650 Kg/Cm² min.</td>
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<tr>
<td>Fitting</td>
<td>Pipe Fitting</td>
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<td>500</td>
<td>&gt; 135</td>
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<td>45 J/m min.</td>
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<tr>
<td>Profiles</td>
<td>Folding Door</td>
<td>-</td>
<td>1.48</td>
<td>390</td>
<td>&gt; 12</td>
<td></td>
<td>60 J/m min.</td>
<td>700 Kg/Cm² min.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Film</td>
<td>Cellophane</td>
<td>Transparent</td>
<td>1.37</td>
<td>180</td>
<td></td>
<td>65 J/m min.</td>
<td>800 Kg/Cm² min.</td>
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</table>
# PVC Compound Flexible Specifications

<table>
<thead>
<tr>
<th>TYPE</th>
<th>GRADE</th>
<th>Colour</th>
<th>Shore &quot;A&quot; Hardness</th>
<th>Relative Density max.</th>
<th>Tensile Strength Kg/Cm²</th>
<th>Elongation Break mm</th>
<th>Cold Flex C min</th>
<th>Volume Resistivity Ohm.Cm</th>
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</thead>
<tbody>
<tr>
<td>CABLES</td>
<td>I.C</td>
<td>Natural</td>
<td>75 - 85</td>
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<td>160</td>
<td>250</td>
<td>14</td>
<td>10¹³</td>
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<tr>
<td></td>
<td>SHEATH</td>
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<td>70 - 80</td>
<td>1.50</td>
<td>140</td>
<td>330</td>
<td>12</td>
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<td>FILLING</td>
<td>Natural</td>
<td>75 - 85</td>
<td>1.50</td>
<td>140</td>
<td>250</td>
<td>- 17</td>
<td>10¹⁴</td>
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<td></td>
<td>A4</td>
<td>Natural</td>
<td>75 - 85</td>
<td>1.35</td>
<td>175</td>
<td>200</td>
<td>- 17</td>
<td>10¹⁵</td>
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<td>A5</td>
<td>Natural</td>
<td>90 - 95</td>
<td>1.40</td>
<td>225</td>
<td>250</td>
<td>- 20</td>
<td>10¹⁴</td>
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<tr>
<td>SHOES</td>
<td>SH-55</td>
<td>Transparent</td>
<td>55 - 60</td>
<td>1.16</td>
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<td>SH-60</td>
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<td>SH-70</td>
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<td>SH-75</td>
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<td>70 - 75</td>
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<td>220</td>
<td>320</td>
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Thank You